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MEMORANDUM REPORT NO. 1738

THE DEVELOPMENT OF A HIGH ACCELERATION TESTING TECHNIQUE FOR THE ELECTRONIC INSTRUMENTATION OF HARP PROJECTILE SYSTEMS

by

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March 1966

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BALLISTIC RESEARCH LABORATORIES
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THE DEVELOPMENT OF A HIGH ACCELERATION TESTING TECHNIQUE FOR THE ELECTRONIC INSTRUMENTATION OF HARP PROJECTILE SYSTEMS

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A B E R D E E N   P R O V I N G   G R O U N D,   M A R Y L A N D

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

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Aberdeen Proving Ground, Md.
March 1966

THE DEVELOPMENT OF A HIGH ACCELERATION TESTING TECHNIQUE FOR THE ELECTRONIC INSTRUMENTATION OF HARP PROJECTILE SYSTEMS

ABSTRACT

A brief description of Project HARP (High Altitude Research Project) is given, and the acceleration testing requirements for the electronic instrumentation of the projectiles are stated. The acceleration testing methods which have previously been employed are reviewed. A BRL project for the development of a satisfactory acceleration testing technique for this purpose is described, and test results are given. These test results are analyzed, and test criteria are established and evaluated.

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1. INTRODUCTION

1.1 Project HARP

Project HARP (High Altitude Research Project),[1-10*] of the U.S. Army Ballistic Research Laboratories (BRL)) uses smooth-bore 5-inch, 7-inch, and 16-inch guns to launch sub-caliber saboted projectiles for upper atmosphere research. The projectiles contain instrumentation that is partially of a passive nature: chaff, chemicals, parachutes, and balloon packages for wind measurement;[11,12] and partially of an active nature: flash units, grenades, and temperature, pressure and ion-sensors with on-board telemetry.[13-17]

1.2 The Testing Problem

The instrumentation components for Project HARP must withstand high accelerations (tens of thousands of g's), and in the development stage pretesting to determine survival limits is required. In the case of critical mechanical components and ordnance items, whose failure could lead to vehicle breakup and hence to gun damage, the practical solution was simply to over-test and provide added insurance. The procedure used here was to assume a pessimistic upper bound on the g load, namely that the vehicle felt the maximum gun chamber pressure in a static state, i.e.,

$$\frac{\pi d^2 P_{max}}{4 m_p} ,$$

where d = diameter of probe sabot in inches,

P_{max} = breech pressure in lb/in^2, and

m_p = weight of probe in lbs.

This load level was "duplicated" by launching the vehicle "softly" and impacting it into a lead block until a copper ball accelerometer registered the desired load level. There was every indication that this procedure was an overtest by about a factor of two.

* *Superscript numbers denote references which may be found on page 38.*

The development of some of the electronic packages indicated that these high test requirements, if used on the electronic components, would impose a very significant cost in development time and money and, probably, in the cost of the end item. Therefore, a program was initiated to determine a minimal test level and methods that would yield an adequate survival ratio without too high a rejection ratio of components and subsystem designs. The objective of the program was to determine a test procedure that would:

(1) permit recovery and post-examination of components,

(2) yield a minimal adequate test level to qualify components,

(3) be economical and convenient, and

(4) lead to only "occasional" failure of the parts qualified in ground tests.

The possibility of an occasional failure was acceptable because, first, it was economical and, second, it was tolerable, since an instrumental failure incurred no risk to the launcher and posed no flight safety hazard.

1.3 Selection of Testing Procedure

The selection of an adequate test model for a minimal safety factor involves much more soul searching than that for one with a high safety factor. In the present case it was decided to utilize the acceleration profile from an interior ballistic computation of a quite complete nature for the worst test condition contemplated. Modern interior ballistic computations require a high-speed computer and also contain assumptions that are questionable when projectile velocities exceed 5,000 ft/sec. A number of inputs to the computation have to be determined from experimental results; the procedure used is to make trial runs, using the computational model, until the values selected for the "shot-start", bore-resistance, and the burning-rate result in a match of the measured velocity and pressure for a range of test conditions. In such a case, even if the model is slightly imperfect, there is only a small chance that the acceleration profile so computed is locally in error at critical

regions by more than, say, 10 percent. This procedure was followed for the guns used in the HARP project, and the profiles selected are given in Figure 1.

The computed peak accelerations are of the order of 30,000 g for the 5-inch gun and 15,000 g for the 7-inch and 16-inch guns. The average accelerations are about 16,000 g for the 5-inch gun and 8,000 g for the 7-inch and 16-inch guns. The acceleration durations are about 10 milliseconds in the 5-inch gun and about 20 milliseconds in the 7-inch and 16-inch guns.

The simulation of these gun probe acceleration pulses for the preflight testing of electronic instrumentation for HARP projectile systems was not an easy task, since it was difficult under test conditions to duplicate the high peak accelerations, the pulse shapes, and the acceleration durations which are typical of gun probe firings. Moreover, the testing program required that the instrumentation be recovered intact.

Similar acceleration testing problems have been encountered at other laboratories, and sizeable programs have been conducted to solve them. Some testing methods are given below:

(1) Centrifuge testing techniques - Employed at many installations but generally limited to several thousand g's and a slow rate of onset.

(2) Air guns launching the test object into a deceleration tube - The object is decelerated as it compresses a gas, and the deceleration history is determined by metering the outflow of the decelerating gas volume (the 200-foot long air gun-deceleration system at Picatinny Arsenal is an example).

(3) Air gun launching system with recovery of the test object after impact in media denser than air - Test g load is created at impact. As generally used, the peak g pulse can be high but the duration is short, about a millisecond. (A typical installation is at the Harry Diamond Laboratories).

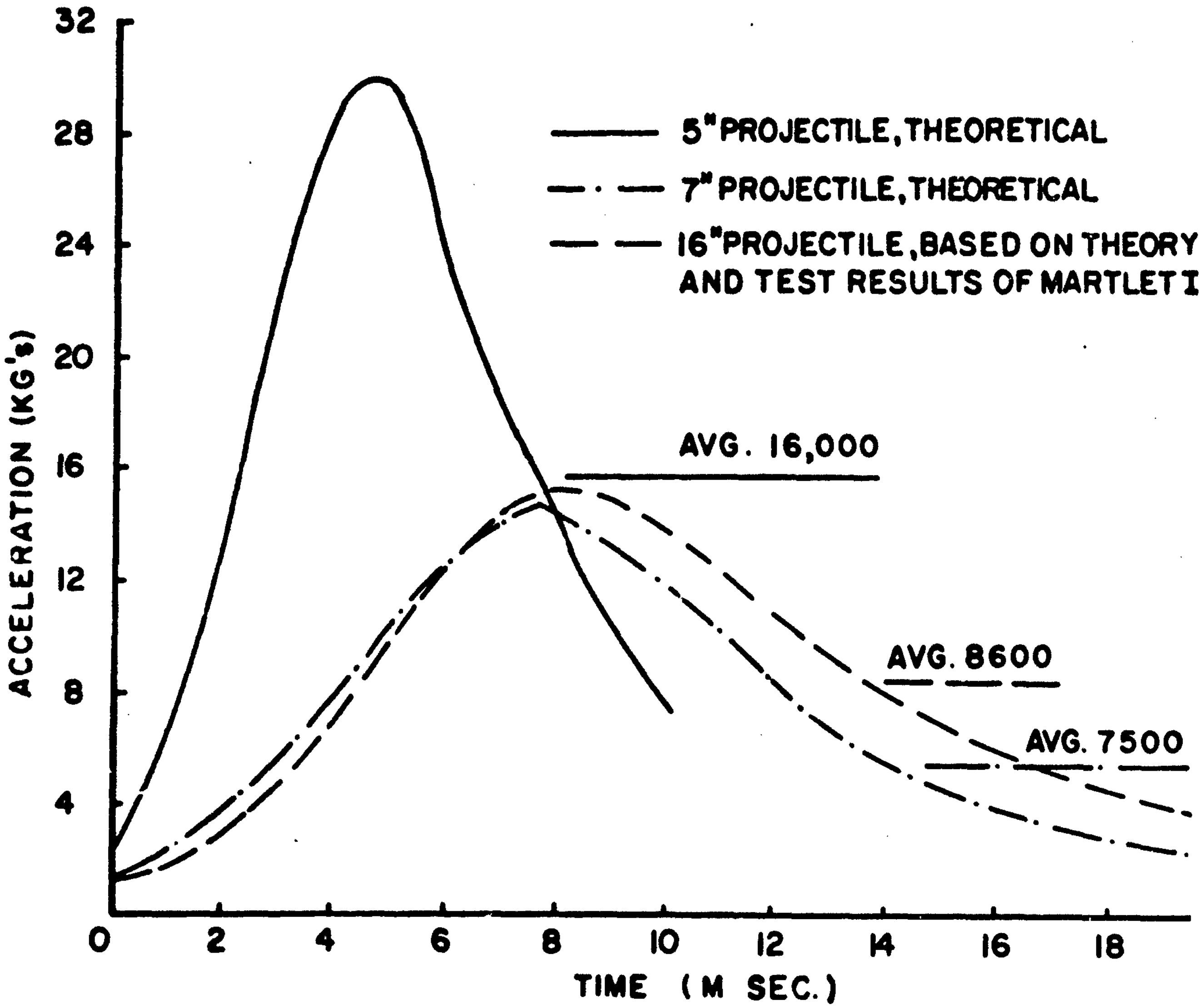

FIG. I PROJECTILE ACCELERATION vs TIME IN GUN (THEORETICAL)

(4) Powder gun launching - Except for the propelling medium, this system has the characteristics of (3). (A temporary installation of this type was set up at Aberdeen Proving Ground, (APG) to test certain Harry Diamond Laboratories pyrotechnic units which could not be tested at that installation because of safety considerations.)

(5) Direct gun launching - Simulating accelerations experienced by the projectile during the launch phase. While it is not necessary to launch the exact flight projectile, in general a relatively heavy projectile would be placed in flight at high velocity to meet the HARP requirements. Mud flats, shallow lakes, etc., have been used as recovery areas and under the best conditions are useful, but frequently recovery is expensive and successful recovery ratio low.

After a review of the possible systems, it was decided to consider initially only systems that could be conveniently employed at APG. The alternatives that seemed most worthy of consideration were:

(1) Direct launch (g's simulated in gun)
   a. from a 57mm gun; projectile would impact in the mud impact area used for shell recovery at APG.
   b. from the 5-inch gun; drag brakes used to slow the projectile rapidly enough so that impact would be "soft" and at a short enough range so that visual observation could be used to aid recovery.

(2) Low-speed launch with the g load experienced at impact, try to control the pulse level and duration by altering the shape of the nose of the impacting projectile and, if required, by the use of different impact media. Two possible launch systems were considered:
   a. the 5-inch (127 mm)gun used in the earlier HDL tes
   b. an air gun installation that had been deactivated many years ago by Development and Proof Services.

Approach (1)-a was tried, but after several attempts the recovery ratio proved to be totally unacceptable. A serious design evaluation was also made of (1)-b, and it become clear that any deceleration carrier vehicle that had a chance of yielding a good recovery ratio would be quite expensive. The choice then narrowed to (2)-a and (2)-b; and, at least for initial tests, there seemed to be no visible gain in the use of the air gun that would weigh against the reactivation costs.

The exploration and evaluation of the (2)-a system will be detailed in the remainder of the report.

2. TEST PROGRAM

2.1 Basic Concept

The BRL high acceleration testing program for the electronic instrumentation of Project HARP projectiles consisted essentially of a series of low muzzle velocity firings (500 ft/sec to 1400 ft/sec) from a smoothbore 5-inch gun for the purpose of exploring the effects produced when test projectiles with conical nose tips of various included angles struck lead targets. The launch accelerations were less than 1,000 g. Momentum levels between 400 lb-sec to 1300 lb-sec were selected. A 2 1/2-inch radius hemispherical nose tip was also used to provide correlation with result of previous tests conducted at Harry Diamond Laboratories.

2.2 Test Series Detail

The first series of rounds, using projectiles which had the various nose tips and approximately the same momentum levels, was fired to investigate the peak deceleration and average deceleration versus time duration of impact relationships for each nose tip.

A second series of rounds was fired to investigate the effects of momentum upon peak and average decelerations and time of impact durations for the 75° nose tip.

A third series of rounds was fired to investigate the effects of momentum upon the deceleration characteristics of projectiles with 30°, 45°, and 60° nose tips.

A fourth series of rounds to investigate impact media other than lead was planned, if required.

3. TEST EQUIPMENT

3.1 Test Setup

The test setup for this project is shown in Figure 2.

3.1.1 5-Inch Gun. The gun used to propel the test projectiles (containing the components to be tested) was a 5-inch T66 E3 smoothbore powder gun. This gun was readily available, as were experienced personnel to fire it.

3.1.2 Propellant. The propellant used in all tests was a HPC smokeless M2 powder for 75 mm guns. This is a fast burning propellant for a 5-inch gun, which requires only small amounts of powder (6 to 28 ounces by weight) to achieve the pressure necessary to launch the test projectiles. The propellant was loaded into a bag which was placed around an M67 electric-percussion primer in a standard brass case.

3.1.3 Test Projectiles. The test projectiles consisted of three parts: (1) the body, an aluminum section 4.995 inches in diameter and 10.25 inches in length, containing a cavity into which the instrumentation components were placed; (2) a steel nose, which carried a ball accelerometer, and was screwed to the body; and (3) a base closure plate with a 12-inch rod extending rearward for measurement purposes (Figures 3 and 4). Both conical and hemispherical noses were used. The conical noses had included angles of 30, 45, 60, 75, and 90 degrees, and the hemispherical nose had a radius of 2 1/2 inches (Figure 5).

3.1.4 Targets. The cast lead targets had 12-inch-square faces and a depth of 5 1/2 inches. Each target weighed 315 pounds. The targets were placed on a steel pedestal and butted against a concrete back stop.

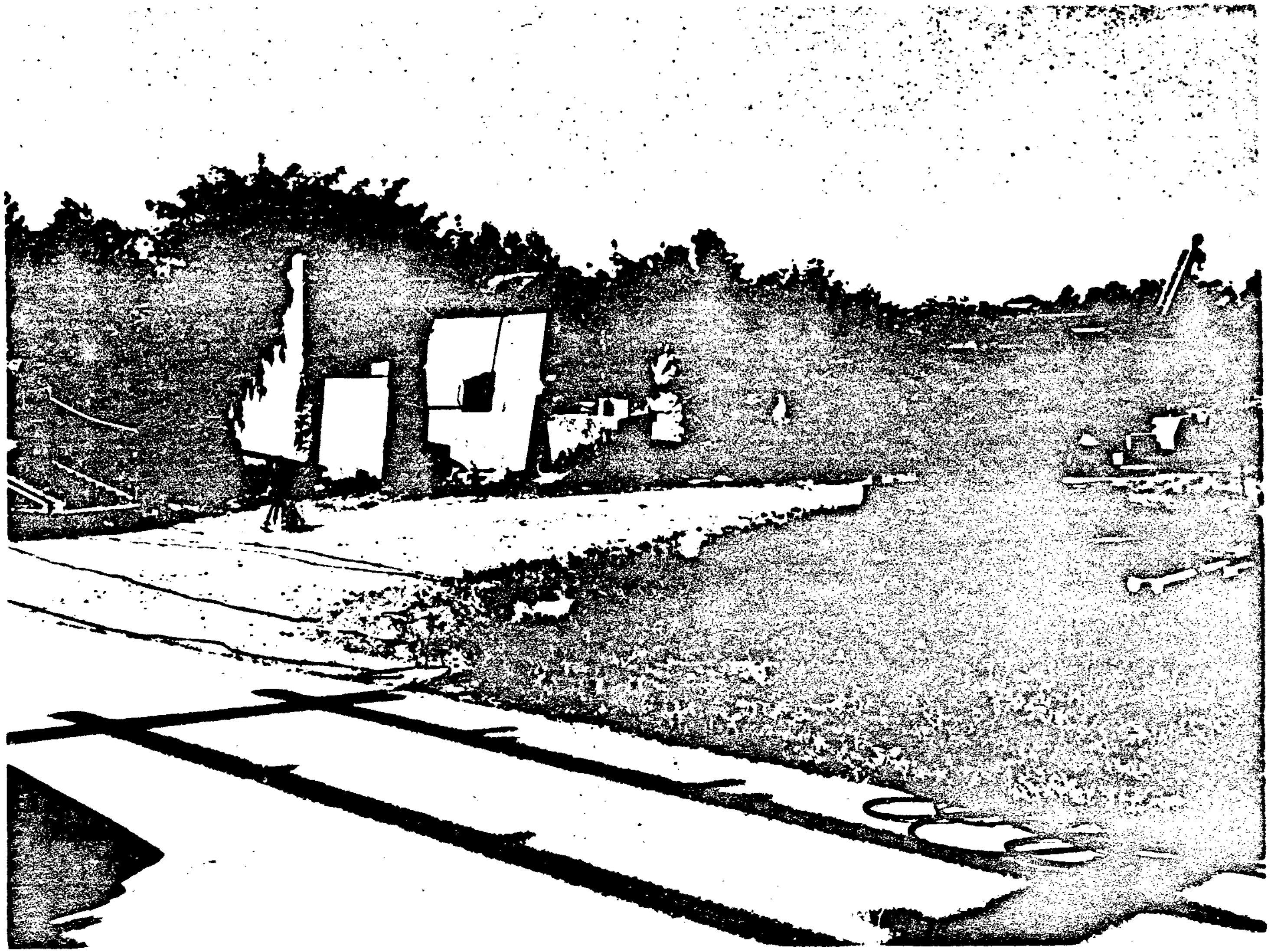

FIGURE [illegible] TEST SETUP

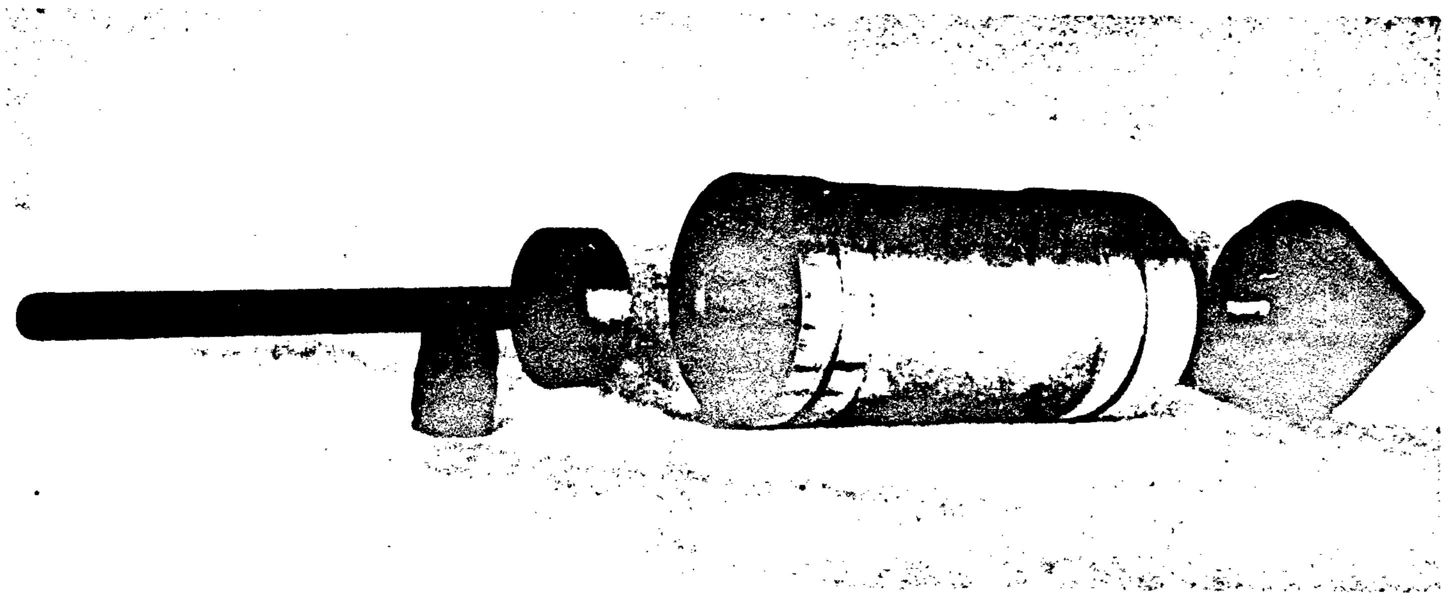

FIGURE 3. TEST PROJECTILE PARTS

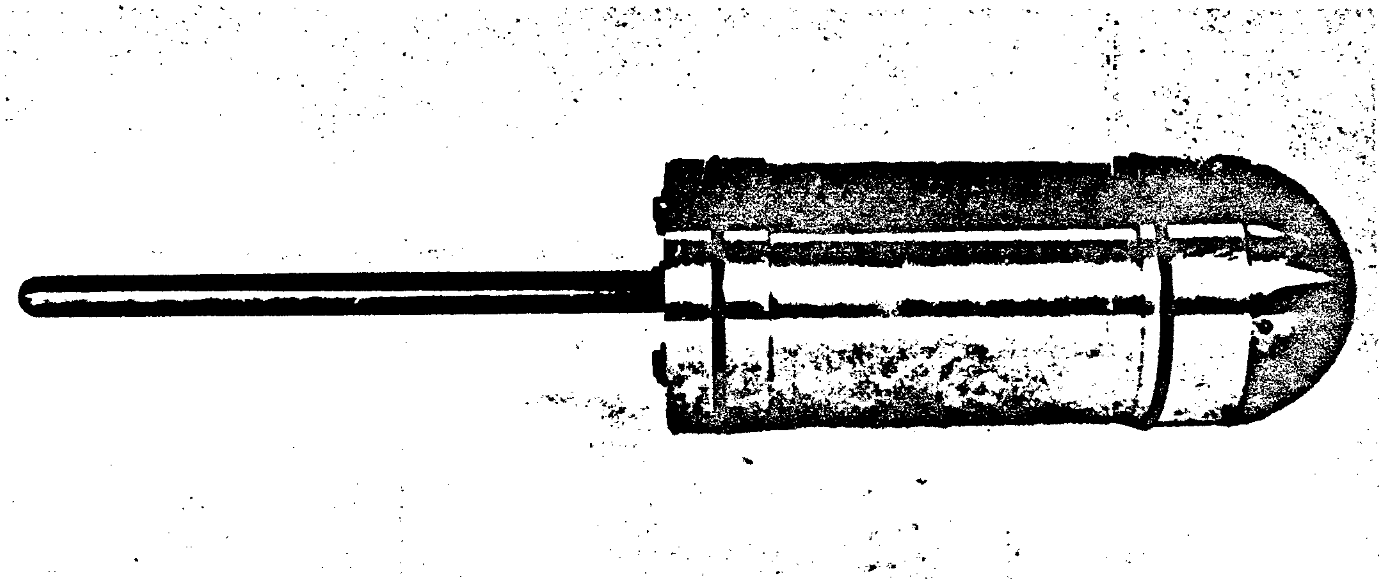

FIGURE 4. TEST PROJECTILE ASSEMBLED

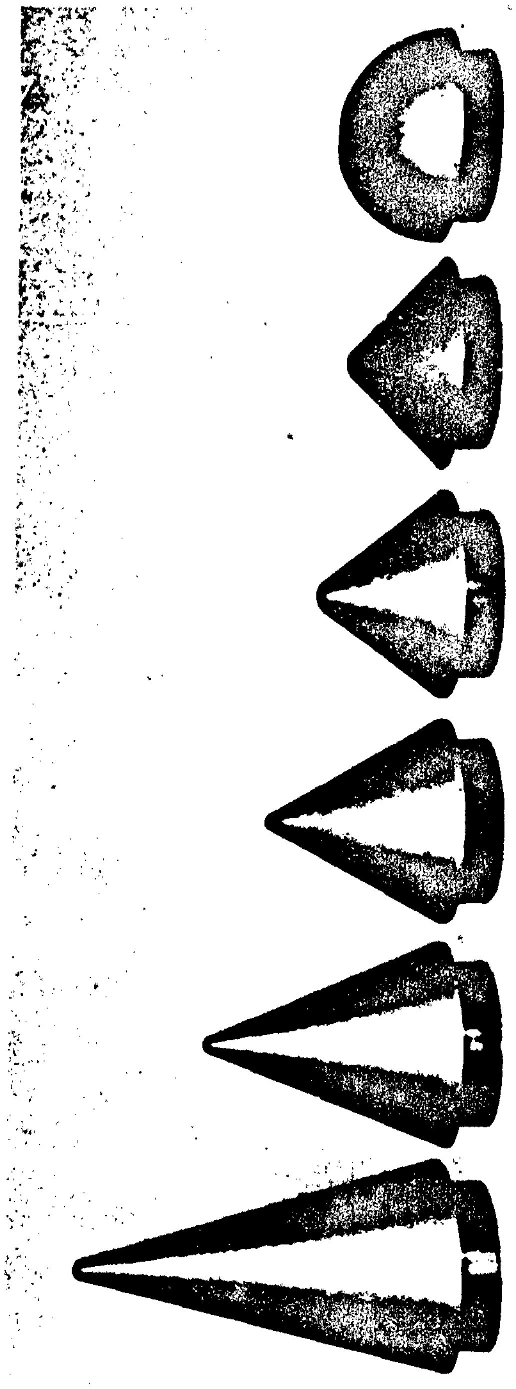

FIGURE 5. TEST PROJECTILE NOSE TIPS

From three to eight targets were employed face to face for each test, the number varying with the amount of penetration which was anticipated. Once used, the targets were melted down and recast into new ones; approximately 15 percent of the lead was lost during each test because of splattering effects (Figure 6).

3.2 Instrumentation

3.2.1 Skyscreens. The test projectile velocities between the gun and the targets were measured by skyscreen equipment. The two field skyscreens were connected to a 1.6-megacycle counter with a master-oscillator. Passage of the projectile across one skyscreen started the counter and the projectile passage across the second stopped the counter; thus the time to traverse a known distance was measured and hence the projectile velocity could be calculated.

3.2.2 Fastax Cameras. The test projectile velocities immediately prior to impact, and the deceleration times of the test projectiles as they penetrated the targets, were measured by a Fastax camera which was placed at a right angle to the target and the line of fire. Time information was provided by millisecond timing marks that appear on one edge of the film. A WF301 Goose control unit was used to run the camera, and a sequential timer was employed to start the camera control unit, initiate the time base for the camera, and fire the gun. The 12-inch steel rods attached to the rear of the test projectiles facilitated measurements during deep target penetrations.

3.2.3 Accelerometer Units. Copper ball accelerometer units, developed by the Naval Ordnance Laboratory, were installed in the test projectiles to measure impact decelerations. These units, Figure 7, consisted of a steel base or anvil on which a 0.156-inch-diameter copper ball was placed and held in position by a small piece of rubber tubing. An aluminum housing was screwed to the steel base. This housing contained a steel piston which rested against the copper ball. The ends of the piston were segments of a 1.5-inch-diameter sphere. The piston was held

FIGURE 6. LEAD TARGETS

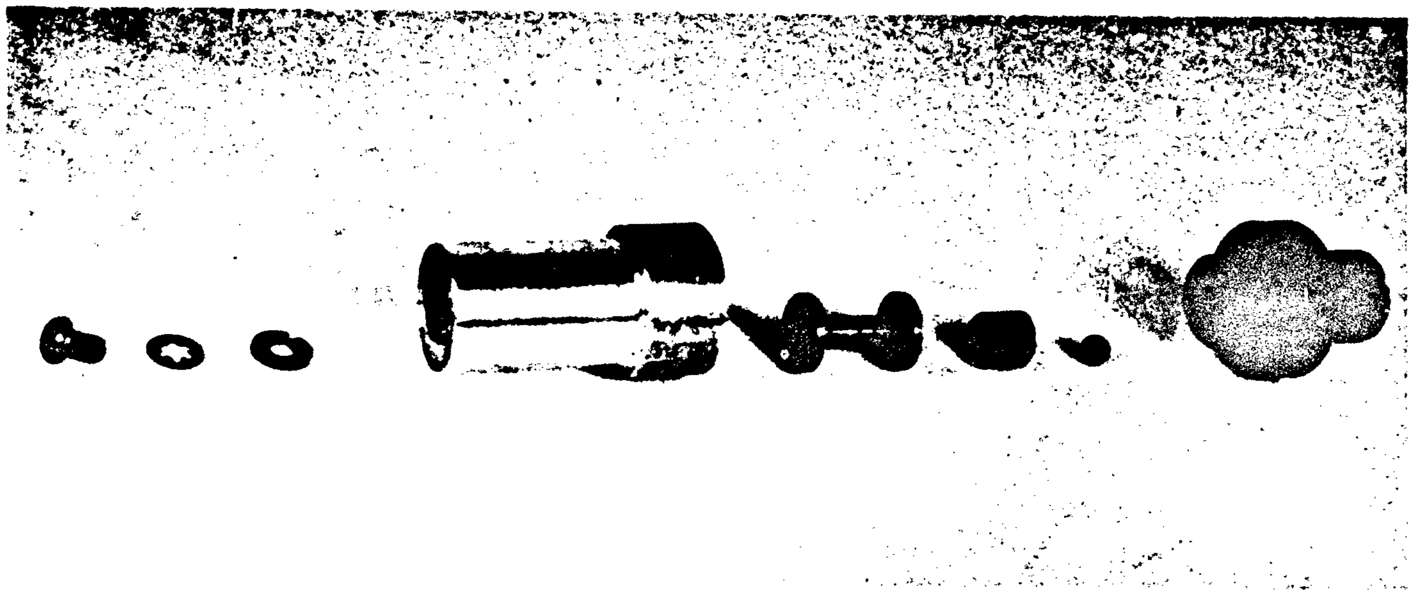

FIGURE 7. ACCELEROMETER PARTS

firmly against the copper ball by a screw in the end of the housing. The fully assembled accelerometer units were mounted on the base of the test projectile nose tips. Upon impact, the piston drove against the copper ball and deformed it; the amount of deformation was proportional to the deceleration.

4. TEST RESULTS

4.1 First Test Series. The test projectile velocity data obtained from the skyscreens during the first series of rounds showed that the equipment did not function satisfactorily because of the close proximity of the gun muzzle. The gun gases caused multiple triggering of the counter system, resulting in erroneous readings. In one series of thirteen rounds, only one skyscreen velocity measurement was credible. (The use of skyscreens was then abandoned.) The inadequacy of skyscreen data necessitated complete reliance on Fastax camera data.

The Fastax camera data were used to find the projectile velocity at impact, the penetration during impact, and the peak and average deceleration of impact. Figure 8 shows the raw film data for Round 6891, which used a projectile with a 75-degree included angle nose tip at a momentum level of 1115 lb-sec. The bright spots at the left edge of certain frames are 1-millisecond timing marks. Distances were measured from the right extremity of the frame to the tip of the one-foot-long rod that projected rearward from the base of the test projectile. The rod not only acted as a reference point for time-versus-displacement measurements but also gave a reference length to establish proper scale factors for data reduction. Figure 9 shows the test projectile penetration versus time derived from the film shown in Figure 8. The test projectile deceleration-versus-time profile is shown in Figure 10.

The forced reliance upon Fastax camera data caused an investigation of different data reduction procedures. Initially, the average deceleration was obtained by two methods: one method was to find the area under the deceleration curve (Figure 10) and divide by the total time, and the

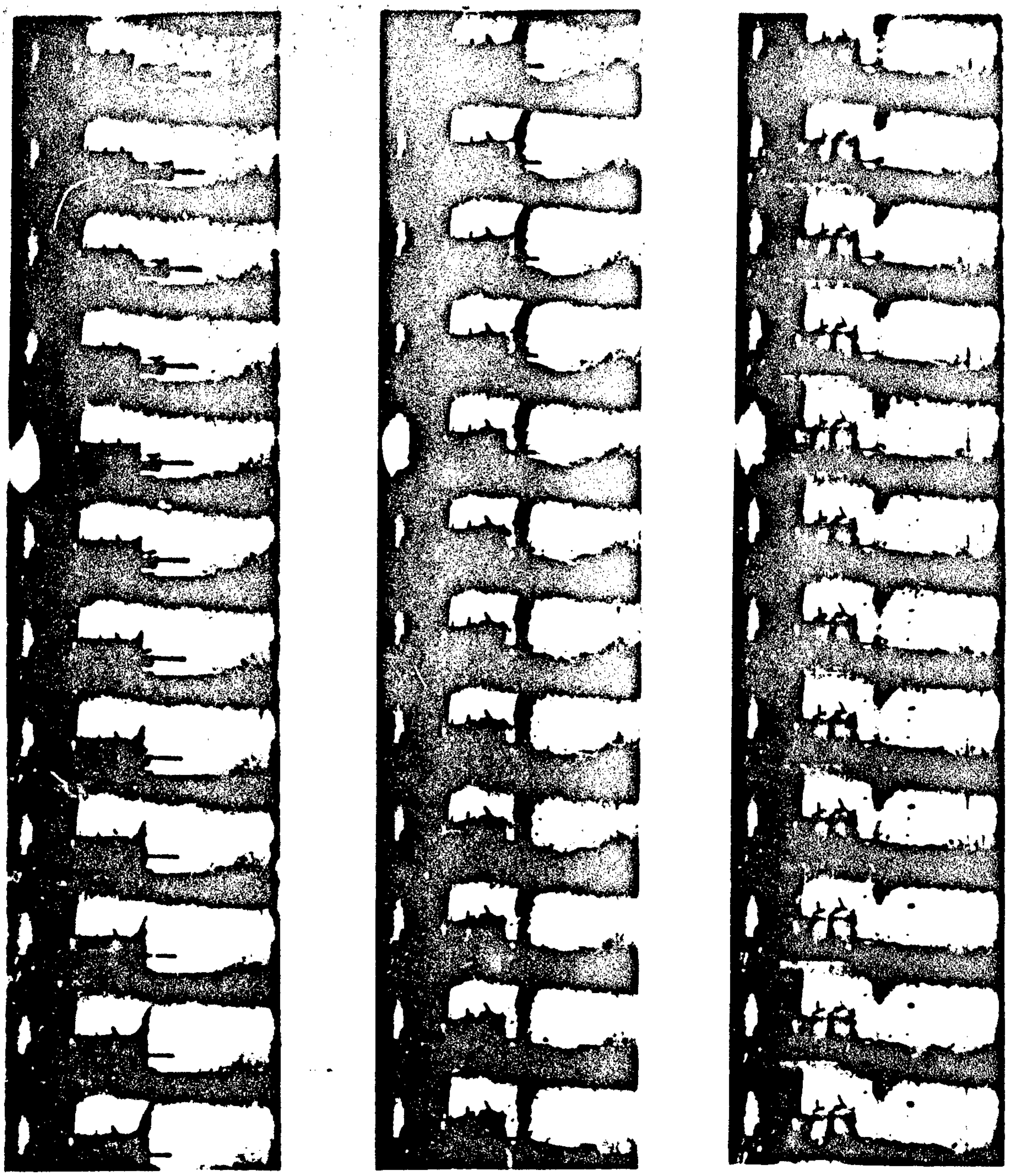

FIGURE 8. TEST PROJECTILE IMPACTING ON LEAD TARGETS

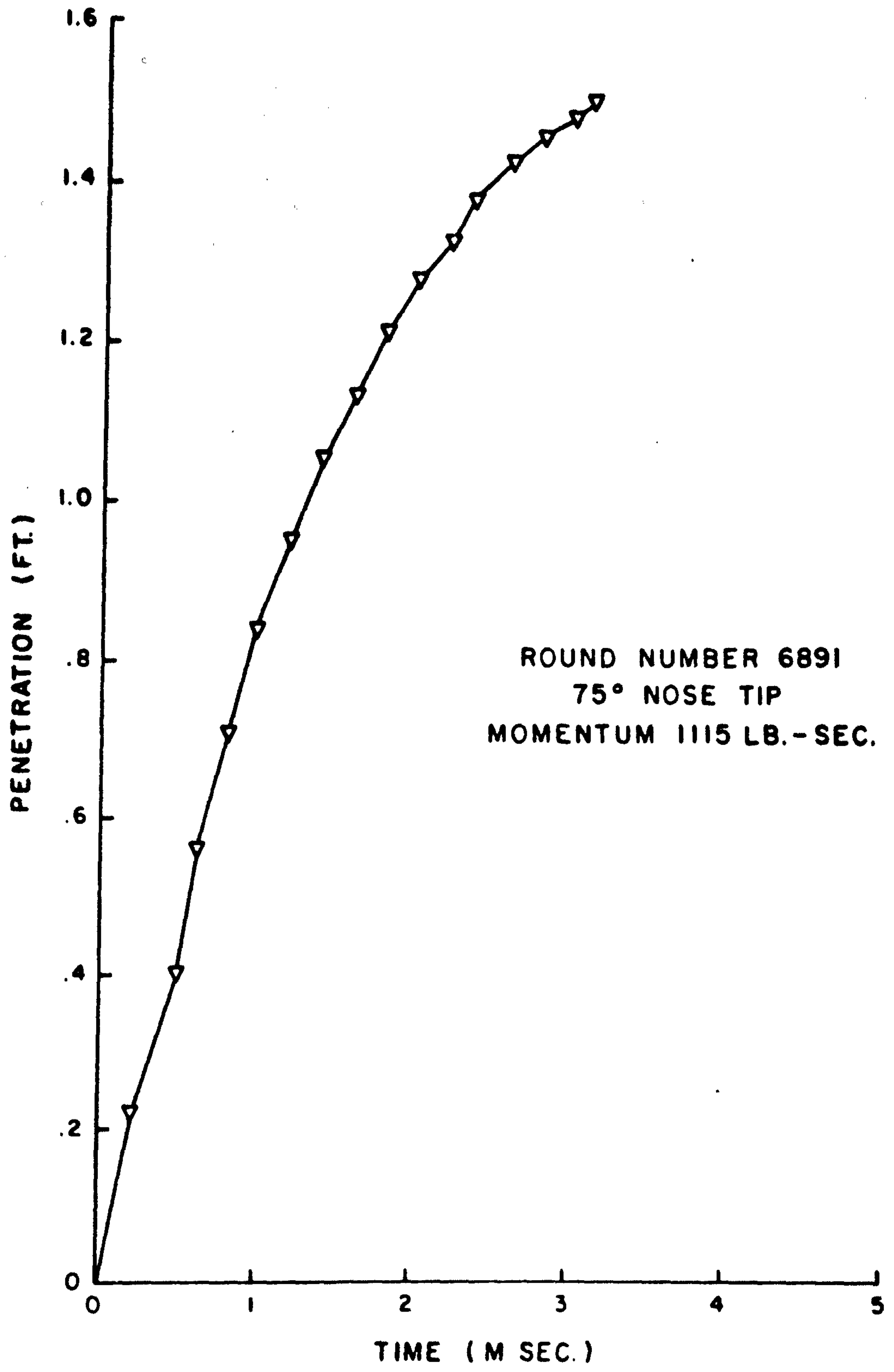

FIG. 9 - TEST PROJECTILE PENETRATION

VS.

TIME

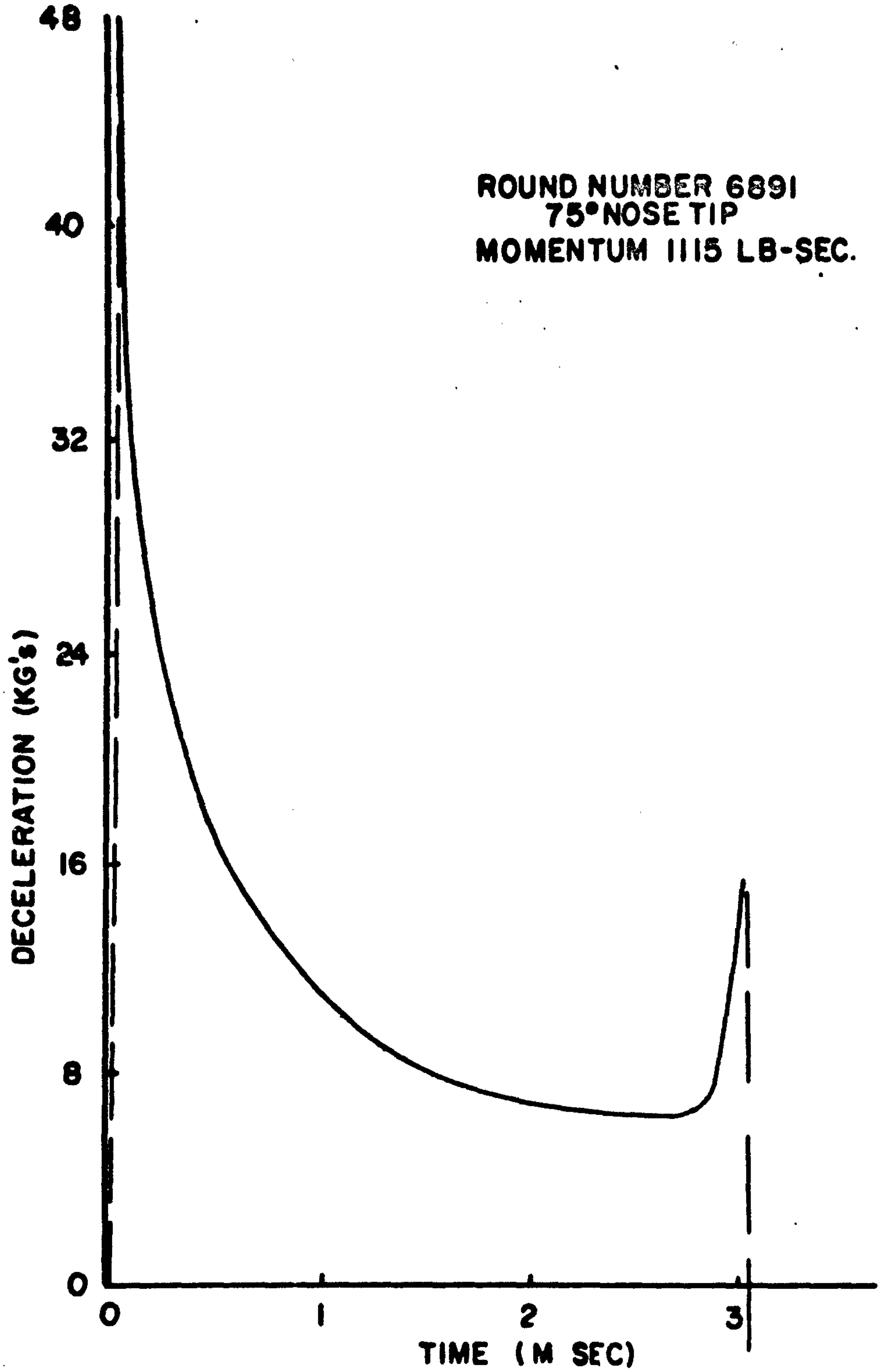

FIG. 10 TEST PROJECTILE DECELERATION
VS
TIME

other method employed the motion equation assuming a constant deceleration. The motion equation provided four basic identities:

$$\bar{A} = \frac{V_o}{t_p} \text{ ft/sec}^2 \tag{1}$$

$$\bar{A} = \frac{2x_p}{t_p^2} \text{ ft/sec}^2 \tag{2}$$

$$\bar{A} = \frac{V_o^2}{x_p} \text{ ft/sec}^2 \tag{3}$$

$$\bar{A} = -2\left(\frac{V_o t_p - x_p}{t_p^2}\right) \text{ ft/sec}^2 \tag{4}$$

where $\bar{A}$ is the average deceleration in ft/sec^2,

V_o is the initial impact velocity in ft/sec,

x_p is the total penetration in feet, and

t_p is the total time of impact in seconds.

The integral and motion equation methods for obtaining average deceleration were compared on all of the first series of rounds, and it was found that the maximum disagreement was five percent when using identity number (4).

$$\bar{A} = -2\left(\frac{V_o t_p - x_p}{t_p}\right) \text{ ft/sec}^2$$

This gave some degree of confidence in the Fastax measurements, and since the motion equation method was more convenient it was used for the remainder of the test data and gave the values for average deceleration used in this report.

The half frame rate of the Fastax camera did not exceed 12,000 half frames per second, and it could be argued that the maximum values of peak deceleration (Figure 10) as derived from the film data are questionable; however, the data obtained from the ball accelerometers were in close agreement. It appeared that either method could be used to obtain valid peak deceleration data, and both methods were subsequently utilized to obtain the peak deceleration data presented.

The duration of impact was measured directly from Fastax film, and the error of measurement (was) ± 0.15 millisecond for the total impact period.

The data obtained from the first series of rounds (Figure 11) indicated that, as the included angle of the nose tip became more acute, the peak and average decelerations became lower and the duration of impact became longer. The data from the 2 1/2-inch radius hemispherical nose tip rounds were in good agreement with data previously obtained by the Harry Diamond Laboratories.

4.2 Second Test Series

The data obtained from the second series of rounds (Figure 12) showed that the peak and average deceleration and durations were directly proportional to momentum but did not have the same proportionality.

4.3 Third Test Series

The data from the third series of rounds corroborated the results of the first two test series and increased the statistical knowledge of the test system characteristics.

A composite graphical presentation of the data obtained from all of the test rounds is shown in Figure 13.

4.4 Fourth Test Series

The planned fourth series of rounds to investigate impact media other than lead was not carried out because the preliminary evaluation of the first three test phases suggested that an adequate solution had been achieved.

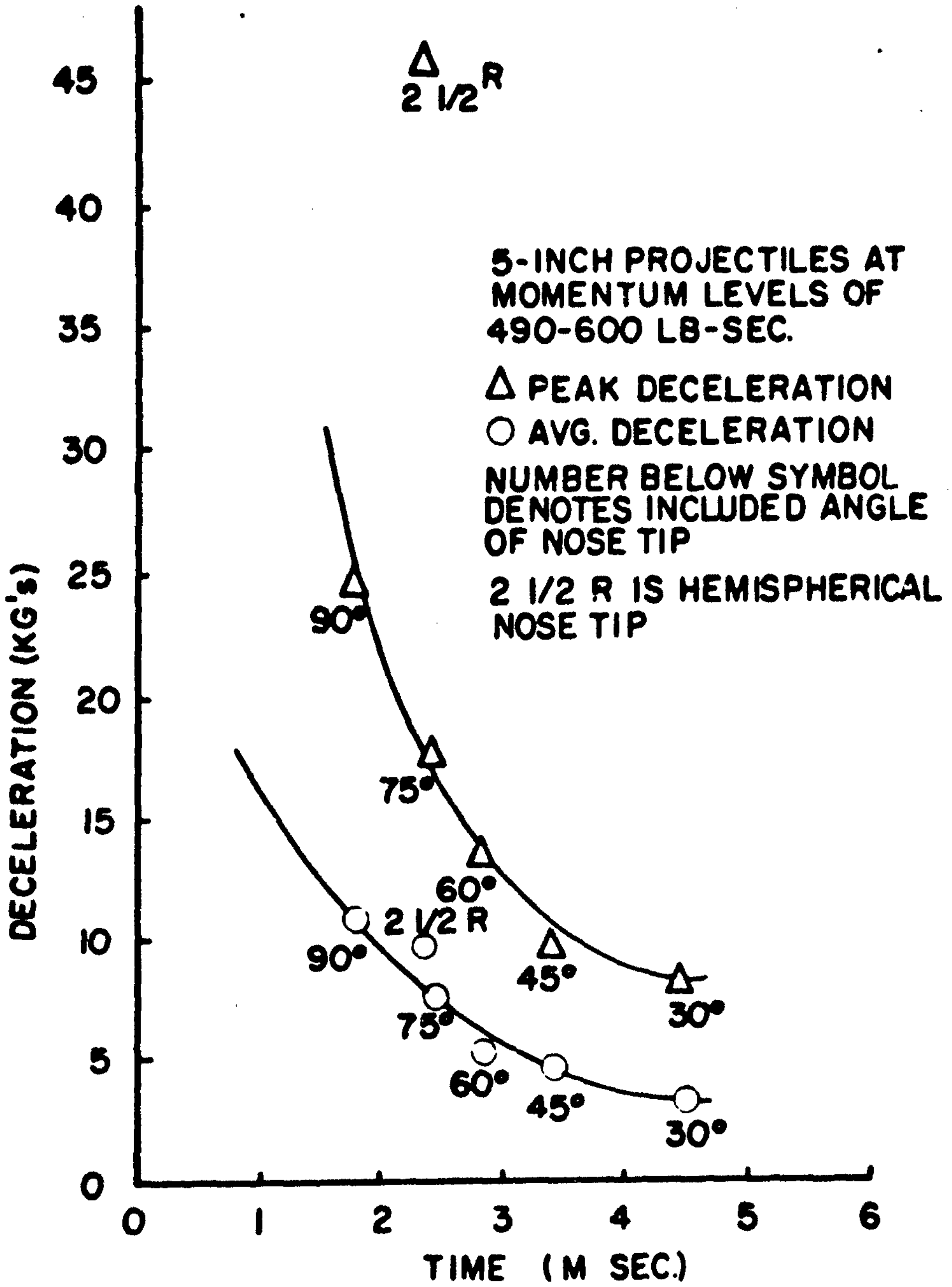

FIG. 11 TEST PROJECTILE PEAK AND AVERAGE DECELERATION vs TIME DURATION (VARIOUS NOSE TIPS)

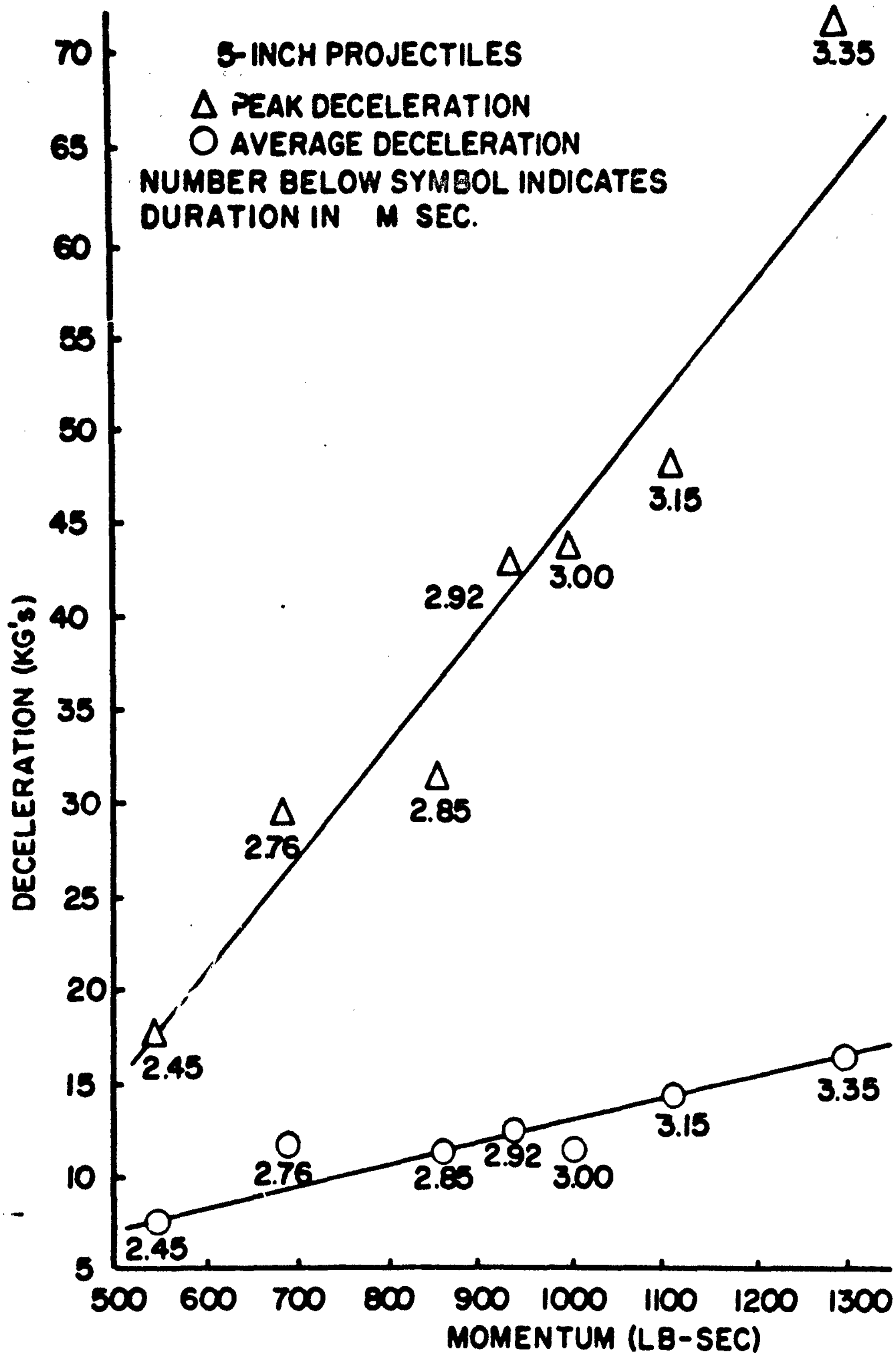

FIG. 12 TEST PROJECTILE PEAK AND AVERAGE DECELERATION vs MOMENTUM (75° CONICAL NOSE TIPPED PROJECTILES)

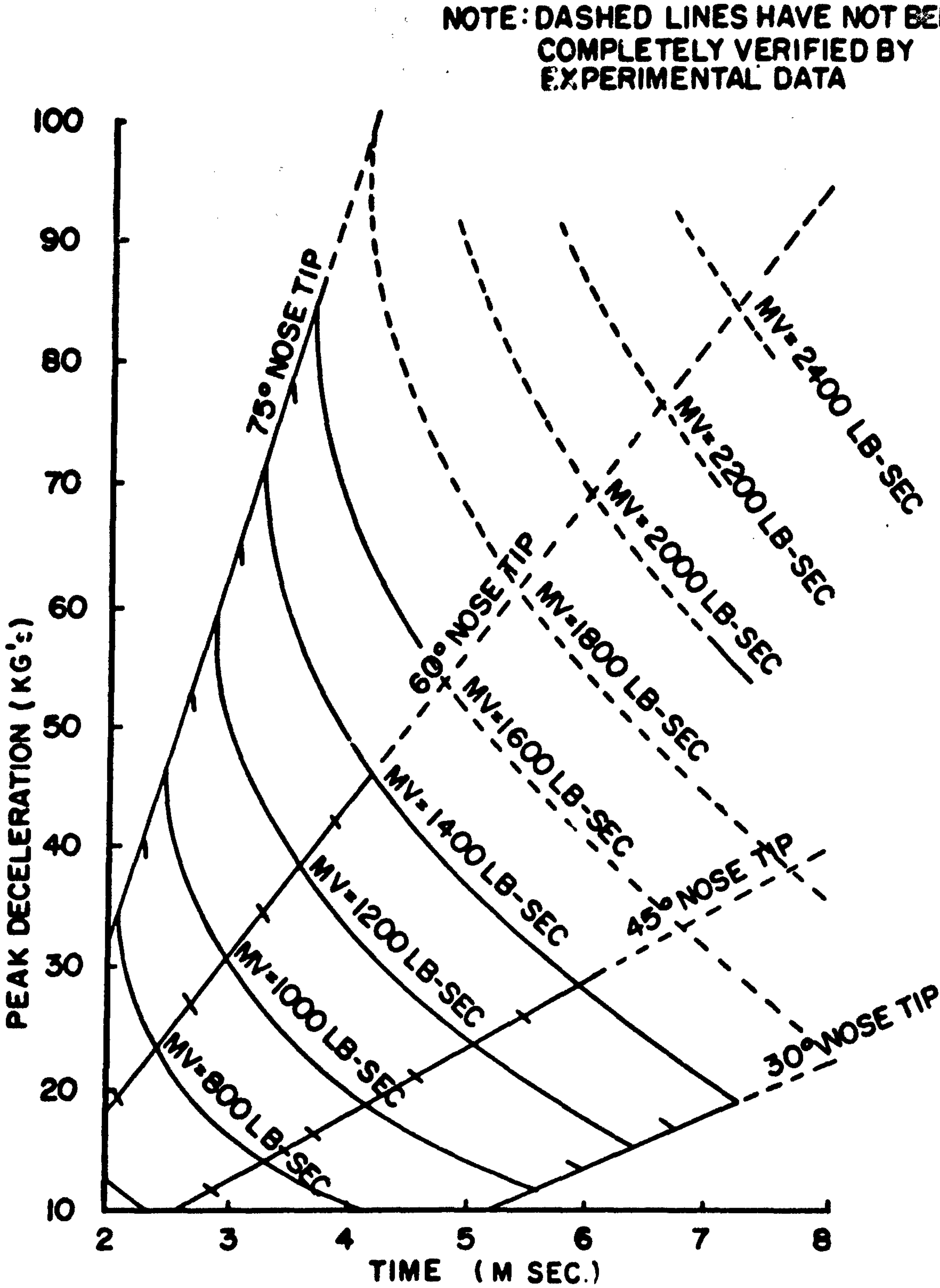

FIG. 13 TEST PROJECTILE PEAK DECELERATION vs TIME DURATION WITH MOMENTUM CURVES (VARIOUS NOSE TIPS)

5. TEST CRITERIA

5.1 Fourier Spectra

An analysis phase was undertaken to find a means of comparing the severity of the lead test with the severity of the gun-launch environment so that realistic criteria for the testing of the electronic instrumentation for HARP projectiles could be established.

The best means available for comparison of test and gun-launch environment severity was the Fourier spectrum.

Fourier spectra were obtained for each gun system and the lead test system. The spectra were obtained by solving the Fourier integral[18,19]

$$\phi(t) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \psi(s) \cos 2\pi f(s - t) ds df \quad ,$$

where $\phi(t)$ is the amplitude of the spectrum,
t is the time of observation,
$\psi(s)$ is the pulse function,
s is time $-\infty \leq s \leq \infty$, and
f is the frequency of interest.

The integral was solved by digital means on the BRLESC computer.

Each Fourier spectrum shows the integral of the shock acceleration response for each frequency in the spectrum. The value of the amplitude of the spectrum at a given frequency is the relative severity of the acceleration that would be experienced by a system resonating at that frequency when subjected to the shock pulse under investigation. Figure 14 shows the Fourier spectra for the 5, 7, and 16-inch guns. Figure 15 shows the Fourier spectra for lead test acceleration pulses of 2, 4, and 8 millisecond durations.

5.2 Comparison of Spectra

The required maximum amplitude of the test pulse was found by the following relationship:

$$AK_1 = BK_2, \text{ or } B = \frac{K_1}{K_2} A$$

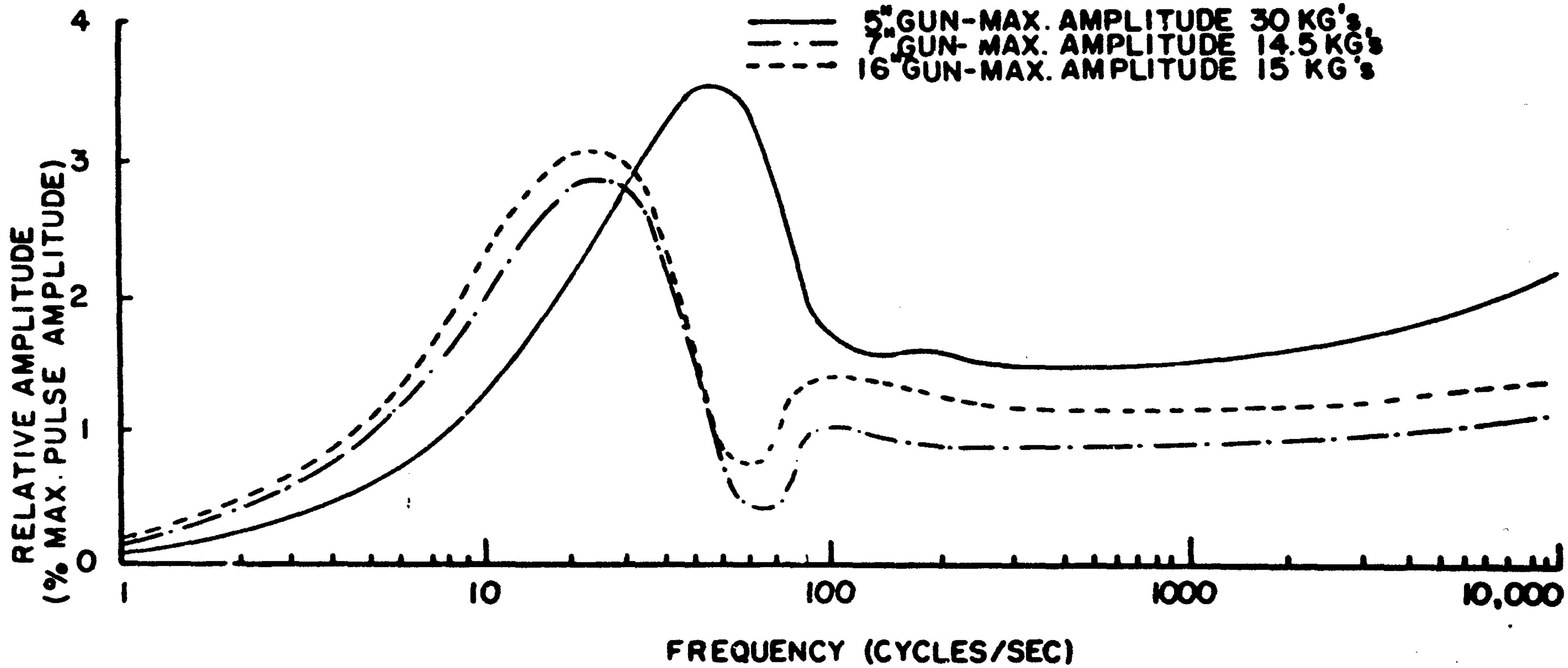

FIG. 14 FOURIER SPECTRA OF 5-INCH, 7-INCH AND 16-INCH GUN PULSES (NORMALIZED AMPLITUDE)

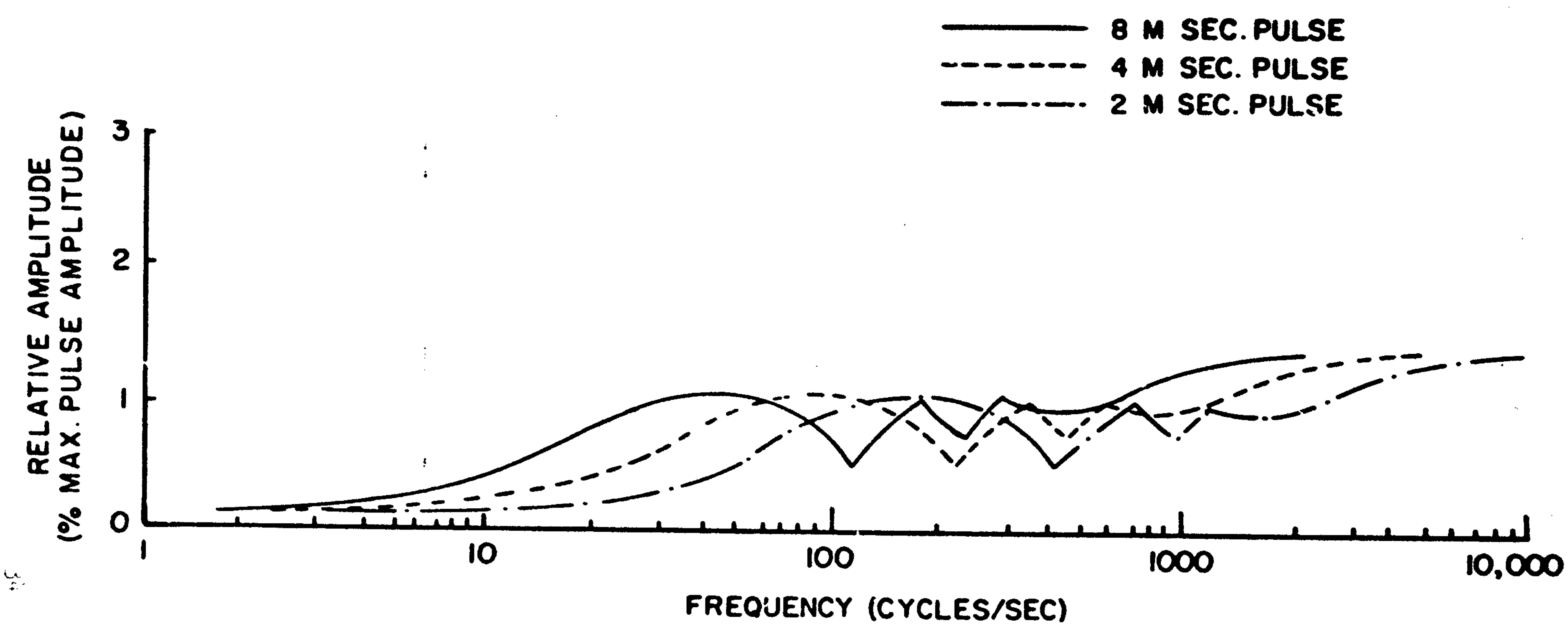

FIG. 15 FOURIER SPECTRA OF 5-INCH TEST PROJECTILE IMPACTS ON LEAD TARGETS (NORMALIZED AMPLITUDE)

where A is the maximum gun pulse acceleration in kilo-g's,

K_1 is the relative severity in percentage of maximum amplitude at a specific frequency on the gun-pulse spectrum,

B is the maximum amplitude of the lead test pulse deceleration in kilo-g's, and

K_2 is the relative severity in percentage of maximum lead test pulse amplitude at the frequency of concern on the lead test pulse deceleration spectrum.

5.3 Establishment of Test Criteria

Since the frequency response of the system to be tested was generally unknown, the comparison of the test spectra and the environment spectra had to be made over a band of frequencies in order to establish an adequate test for as many responses as possible without undue overtesting.

It was judged that the frequency band of most importance would lie between 100 cps and 2,000 cps. However, higher frequencies could not be ignored. Therefore, the frequency band of 100 cps to 10,000 cps was taken into account in establishing the test criteria.

A comparison of the curves of Figures 14 and 15 showed that for the 5-inch gun projectile a 3 millisecond pulse with a peak acceleration of 62 kilo-g's would be a valid test for all frequency responses above 85 cycles per second, and that a 4-millisecond pulse with a peak acceleration of 39 kilo-g's would adequately test components for the 7-inch and 16-inch gun projectiles for frequency responses above 40 cycles per second.

By locating the intersection of the peak acceleration and the pulse time duration on the graph in Figure 13, the appropriate nose tip and momentum level was chosen to create the proper test conditions for a given gun probe system. Thus, the following test criteria were established:

(1) To meet the test requirements for the 5-inch gun environment, 75-degree nose-tipped test projectiles must be fired at a momentum level of 1,250 lb-sec, and

(2) for the 7-inch and 16-inch gun environment, 60 degree nose-tipped test projectiles must be fired at a momentum level of 1,325 lb-sec.

6. SUMMARY

6.1 Objectives Accomplished

The acceleration testing program described in this report has accomplished the following objectives:

(1) The feasibility of using the lead impact technique to test electronic instrumentation systems for the HARP projectile has been demonstrated. This technique has the following advantages:

a. It is convenient to use. Once the instrumentation is encapsulated and inserted in the test projectile, the lead targets can be placed on the test pedestal, and the projectiles can be fired into the targets in approximately one half hour.

b. It is reasonable in cost. The amortized test projectile cost is about $20.00 per round. The lead targets cost approximately $27.50 each (including material and labor). The firing cost is about $20.00 per round. The total testing cost ranges from $150.00 to $250.00 per round, depending upon the number of targets used.

c. The instrumentation recovery rate is high. At least 98 percent of the test projectiles and the instrumentation contained therein have been recovered intact.

(2) Test criteria for the use of the lead impact testing technique for this purpose have been established. One test criteria has been established for the electronic instrumentation of the 5-inch gun probe system, and another has been established for the 7-inch and 16-inch gun probe systems.

6.2 Validity of Test Criteria

The validity of the lead impact testing criteria has been verified in practice. Data obtained from the vertical firing tests of HARP

projectiles have shown that 49 of 57, or 86 percent, of the major instrumentation units whose components were pre-flight-tested in accordance with these test criteria have survived the launch accelerations of the gun probe systems (i.e., in cases where the probes left the gun intact).

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Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) U.S. Army Ballistic Research Laboratories Aberdeen Proving Ground, Maryland	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b GROUP

3. REPORT TITLE

THE DEVELOPMENT OF A HIGH ACCELERATION TESTING TECHNIQUE FOR THE ELECTRONIC INSTRUMENTATION OF HARP PROJECTILE SYSTEMS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (Last name, first name, initial)

Marks, Spence T.; Pilcher, James O., II, and Brandon, Fred J.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
March 1966	51	19

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO RDT&E No. 1V014501B53C	Memorandum Report No. 1738
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10 AVAILABILITY/LIMITATION NOTICES

Distribution of this document is unlimited.

11 SUPPLEMENTARY NOTES	12 SPONSORING MILITARY ACTIVITY U.S. Army Materiel Command Washington, D. C.

13 ABSTRACT

A brief description of Project HARP (High Altitude Research Project) is given, and the acceleration testing requirements for the electronic instrumentation of the projectiles are stated. The acceleration testing methods which have previously been employed are reviewed. A BRL project for the development of a satisfactory acceleration testing technique for this purpose is described, and test results are given. These test results are analyzed, and test criteria are established and evaluated.

DD FORM 1 JAN 64 1473

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